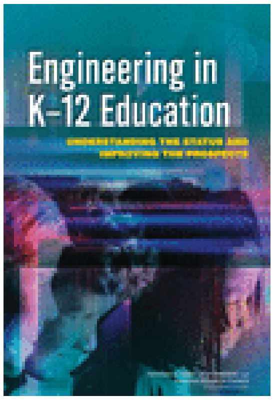

Engineering in K-12 Education: Understanding the Status and Improving the Prospects

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Findings and Recommendations

In comparison to K–12 education in science, mathematics, and technology, K–12 engineering education is still in its infancy in the United States. Nevertheless, we have enough examples of practice to begin to take the measure of this developing academic area. Although more and better impact studies will be necessary in the future, the available evidence shows that engaging elementary and secondary students in learning engineering ideas and practices is not only possible, but can lead to positive learning outcomes.

It is equally clear, however, that the potential effectiveness of K–12 engineering education has been limited by a number of factors, such as challenges associated with curriculum and professional development, difficulties in reconciling this new content with existing curricula in other subjects, the influences of standards-based education reform and accountability,[1] and the absence of teacher certification requirements and pre-service teacher preparation programs. Despite these challenges, it is the committee's judgment, supported by data gathered during the two years of this project, that much can be gained by working to improve the quality and increase the availability of K–12 engineering education.

[1]An ongoing study at the National Academy of Engineering is examining the potential value and feasibility of developing content standards for K–12 engineering education. Information about the project can be viewed at *http://www8.nationalacademies.org/cp/projectview.aspx?key=48942.*

Although improving teaching and learning in this nascent area is important, the committee is even more interested in seeing engineering education become a catalyst for improved learning in the other STEM subjects. Despite all of the concerns by policy makers, educators, and people in industry about the quality of U.S. K–12 STEM education, the role of technology education and engineering education have hardly been mentioned. In fact, the STEM acronym has become shorthand for science and mathematics education only, and even these subjects typically are treated as separate entities.

Finding 1. As STEM education is currently structured and implemented, it does not reflect the natural interconnectedness of the four STEM components in the real world of research and technology development.[2]

The committee believes that the disconnects between STEM subjects has not only impeded efforts to stimulate student interest and improve performance in science and mathematics, but has also inhibited the development of technological and scientific literacy, which are essential to informed citizens in the twenty-first century.

Finding 2. There is considerable potential value, related to student motivation and achievement, in increasing the presence of technology and, especially, engineering in STEM education in the United States in ways that address the current lack of integration in STEM teaching and learning.

In the rest of this chapter, we present the committee's recommendations and remaining findings. Because of the numerous unanswered questions about K–12 engineering education, the findings outnumber the recommendations, which are largely focused on research. We turn our attention first to "defining" engineering in the context of K–12 education. Next we address the scope, nature, and impacts of current efforts to teach engineering to pre-college students in the United States. The following section deals with policy and program issues associated with K–12 engineering education. The chapter concludes with a discussion of fully integrated STEM education.

[2]See, for example, Almeida et al., 2008; Gogate and Kabadi, 2009; and Hood et al., 2008.

GENERAL PRINCIPLES FOR K–12 ENGINEERING EDUCATION

One goal of this project was to clarify the place and "look" of engineering in K–12 classrooms in the United States. Chapter 4 goes a long way toward meeting that goal, but, based on our review of curricular materials, some of what now passes for engineering education is not aligned with generally accepted ideas of the discipline of engineering. We do not mean to suggest that K–12 students should be treated like little engineers or that engineering education in K–12 classrooms should resemble in scope or rigor the post-secondary engineering curriculum. However, we do mean to suggest that in any K–12 school subject for which there is a professional counterpart there must be a conceptual connection to post-secondary studies and to the practice of that profession in the real world.

The absence of standards or an agreed-upon framework for organizing and sequencing the essential knowledge and skills to be developed through engineering education at the elementary and secondary school levels limits our ability to develop a comprehensive definition of K–12 engineering education. Nevertheless, over the course of the committee's deliberations, general principles emerged based on our knowledge of engineering and technology, our review of K–12 engineering curricula, and key documents, such as the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000).

Principle 1. K–12 engineering education should emphasize engineering design.

The design process, the engineering approach to identifying and solving problems, is (1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical; and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis. In all of these ways, engineering design is a potentially useful pedagogical strategy.

Principle 2. K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.

Certain science concepts as well as the use of scientific inquiry methods can support engineering design activities. Similarly, certain mathematical concepts and computational methods can support engineering design, especially in service of analysis and modeling. Technology and technology concepts can illustrate the outcomes of engineering design, provide oppor-

tunities for "reverse engineering" activities, and encourage the consideration of social, environmental, and other impacts of engineering design decisions. Testing and measurement technologies, such as thermometers and oscilloscopes; software for data acquisition and management; computational and visualization tools, such as graphing calculators and CAD/CAM (i.e., computer design) programs; and the Internet should be used, as appropriate, to support engineering design, particularly at the high school level.

Principle 3. K–12 engineering education should promote engineering habits of mind.

Engineering "habits of mind"[3] align with what many believe are essential skills for citizens in the twenty-first century.[4] These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations. Systems thinking equips students to recognize essential interconnections in the technological world and to appreciate that systems may have unexpected effects that cannot be predicted from the behavior of individual subsystems. Creativity is inherent in the engineering design process. Optimism reflects a world view in which possibilities and opportunities can be found in every challenge and an understanding that every technology can be improved. Engineering is a "team sport"; collaboration leverages the perspectives, knowledge, and capabilities of team members to address a design challenge. Communication is essential to effective collaboration, to understanding the particular wants and needs of a "customer," and to explaining and justifying the final design solution. Ethical considerations draw attention to the impacts of engineering on people and the environment; ethical considerations include possible unintended consequences of a technology, the potential disproportionate advantages or disadvantages of a technology for certain groups or individuals, and other issues.

These principles, particularly Principle 3, should be considered aspirational rather than a reflection of what is present in current K–12 engineering education efforts or, indeed, in post-secondary engineering education.

THE SCOPE OF K–12 ENGINEERING EDUCATION

Because of the lack of reliable data, it is impossible to gauge how many U.S. K–12 students have been exposed to engineering-related coursework.

[3]The committee has adopted the term "habits of mind," as used by the American Association for the Advancement of Science in *Science for All Americans* (1990), to refer to the values, attitudes, and thinking skills associated with engineering.

[4]See, for example, The Partnership for 21st Century Skills, *www.21stcenturyskills.org.*

However, because a number of curriculum projects track the use of their materials, we can derive an indirect measure. With a few notable exceptions (e.g., ECCP, 1971), the first formal K–12 engineering programs in the United States emerged in the early 1990s. Since that time, the committee estimates that no more than 6 million K–12 students have had any kind of formal engineering education. By contrast, the estimated enrollment in 2008 for grades pre-K–12 for U.S. public and private schools was nearly 56 million (DOEd, 2008).

Another measure of the scale of K–12 engineering education is the number of teachers involved. Once again, no reliable data are available on this measure. However, most curricular projects include teacher professional development programs or activities and collect information about the individuals who participate in the training. Based on these and related data, the committee estimates that some 18,000 teachers have received pre- or in-service training to teach engineering-related coursework. This estimate does not take into account the nature, duration, or quality of the training, factors that markedly influence whether a participating teacher continues to teach engineering. By comparison, U.S. public and private middle and high schools employ roughly 276,000 mathematics teachers, 247,000 science teachers,[5] and 25,000 to 35,000 technology education teachers[6] (Dugger, 2007; NCES, 2007).

Finding 3. K–12 engineering education in the United States is supported by a relatively small number of curricular and teacher professional development initiatives.

K–12 curricular initiatives have been developed independently, often have different goals, and have been created by individuals with very different backgrounds and perspectives. In addition, the treatment of engineering concepts, engineering design, and relationships among engineering and other STEM subjects varies greatly. For these reasons, it is difficult to compare directly their strengths and weaknesses.

Finding 4. Even though engineering education is a small slice of the K–12 educational pie, activity in this arena has increased significantly, from almost no curricula or programs 15 years ago to several dozen today.

[5]The figures for science and mathematics teachers do not include the over 1 million public and private school elementary school generalists, who are frequently responsible for teaching both subjects.

[6]Variations in research methodologies over the years have resulted in some uncertainty about the exact number of technology education teachers working in the United States.

At this point, it is impossible to predict whether this upward trend will continue, flatten out, or reverse itself. The committee believes that the future of K–12 engineering education will depend at least in part on whether engineering becomes a catalyst for integrated STEM education. (This idea is discussed more fully at the end of this chapter.)

Through the course of the project, the committee has come to appreciate the important role that technology education has played in the development of K–12 engineering education. Indeed, evidence suggests that technology educators form the bulk of the teaching force for engineering in K–12 classrooms, and many curricula intended to convey engineering concepts and skills have been developed in part or whole by those in the field. Given its historical hands-on, project-based emphasis and the more recent focus on technological literacy, it is not surprising technology education has gravitated toward engineering.

IMPACTS OF K–12 ENGINEERING EDUCATION

Finding 5. While having considerable inherent value, the most intriguing possible benefit of K–12 engineering education relates to improved student learning and achievement in mathematics and science and enhanced interest in these subjects because of their relevance to real-world problem solving. However, the limited amount of reliable data does not provide a basis for unqualified claims of impact.

Even fewer quality data are available on the impacts of K–12 engineering education on student engagement, technological literacy, understanding of engineering, and interest in engineering as a possible career. The paucity of data reflects a modest, unsystematic effort to measure, or even define, learning and other outcomes. Before engineering education can become a mainstream component of K–12 education, this information gap must be filled. Without better data, policy makers, teachers, parents, and others with a stake in the education of children will have no basis for making sound decisions.

RECOMMENDATION 1. Foundations and federal agencies with an interest in K–12 engineering education should support long-term research to confirm and refine the findings of smaller studies on the impacts of engineering education on student learning in STEM subjects, student engagement and retention, understanding of engineering, career aspirations, and technological literacy. In addition to looking at impact, researchers should attempt to

ascertain, from a learning sciences perspective, how curricular materials are being used by teachers in the classroom.

RECOMMENDATION 2. Funders of new efforts to develop and implement curricula for K–12 engineering education should include a research component that will provide a basis for analyzing how design ideas and practices develop in students over time and determining the classroom conditions necessary to support this development. After a solid analytic foundation has been established, a rigorous evaluation should be undertaken to determine what works and why.

THE NATURE OF K–12 ENGINEERING EDUCATION

Finding 6. Based on reviews of the research literature and curricular materials, the committee finds no widely accepted vision of the nature of K–12 engineering education.[7]

A lack of consensus does not reflect disagreements among the visions of K–12 engineering education. Rather, it represents ad hoc development and that no major effort has been made to define the content of K–12 engineering education in a rigorous way.

Curriculum Content

Our curriculum review revealed that the central activity of engineering—engineering design—is a dominant feature of most of the curricular and professional-development activities we examined. Both curriculum developers and providers of professional development programs seem to understand engineering design as an iterative, problem-solving process in which multiple solutions are possible. However, the treatment of key ideas in engineering, many closely related to engineering design, is much more uneven and, in some cases, shows a lack of understanding on the part of curriculum developers. Some concepts, such as systems, are generally well explained and appropriately used to support student learning, but others, such as optimization, modeling, and analysis, are incompletely developed or presented in ways that do not reflect their role in engineering practice.

[7]This finding appears to apply also to the non-U.S. pre-college engineering education initiatives considered in this project (see Chapter 4).

One reason for these shortcomings is the absence of a clear articulation of the engineering knowledge, skills, and habits of mind that are most important, how they relate to and build on each other, and how and when (i.e., at what age) they should be introduced to students. As far as the committee knows, no one has attempted to develop a rigorous, systematic specification of age-appropriate learning progressions. A handful of states, most notably Massachusetts (Massachusetts Department of Education, 2006), has developed K–12 curriculum "frameworks" that include a modest degree of engineering content. The majority of state-developed learning goals, however, do not consider engineering at all.

Finding 7. The variability and unevenness in the curricula we reviewed can be attributed largely to the lack of specificity and the lack of a consensus on learning outcomes and progressions.

One approach to addressing this problem might be to develop content standards for K–12 engineering education. After discussing this idea several times, most committee members concluded that, although a thoughtful, authoritative parsing of engineering content appropriate for K–12 would lead to more coherence in teaching and learning, another layer of academic requirements in the current standards-laden U.S. education system would surely meet with strong resistance. A study by the National Academy of Engineering is already under way on the value and feasibility of developing standards for K–12 engineering education, and the results of that study could provide valuable guidance on this important issue.

Curriculum Connections

Finding 8. Existing curricula do not fully exploit the natural connections between engineering and the other three STEM subjects.

The three most important types of interconnection—(1) scientific investigation and engineering design, (2) mathematical analysis and modeling, and (3) technological literacy and K–12 engineering education—are described below.

Scientific Investigation and Engineering Design

Scientific investigation and engineering design are closely related activities that can be mutually reinforcing. Both are methods of solving problems, both must be conducted within constraints, and both require creative thinking, communication, and collaboration. In the curricula we reviewed, we found instances in which scientific inquiry was used to explore the interface between science and technology and, less often, to generate data that could then be used to inform engineering design decisions. We also found numerous instances in which engineering design was used to provide contextualized opportunities for science learning.

A more systematic linkage between engineering design and scientific inquiry to improve learning in both domains has intriguing possibilities. One option, which was evident in several of the curricula we reviewed, is to use engineering as a pedagogical strategy for laboratory activities.

Mathematical Analysis and Modeling

Although mathematical analysis and modeling are essential to engineering design, very few of the curricula or professional development initiatives reviewed by the committee used mathematics in ways that support modeling and analysis. There may be many reasons for this. Curriculum developers may be unfamiliar with how mathematics is used in engineering design or may not understand mathematics learning progressions. Curriculum developers may have concerns about students' mathematical understanding and skills and may be afraid that poor performance would be a barrier to exposing students to engineering material.

Despite the paucity of mathematics in most curricula, the committee believes that K–12 engineering education could contribute to improvements in students' understanding and performance on certain areas of mathematics. For example, numerical manipulations required for measurements and analyses associated with engineering design may, through exposure and repetition, increase students' confidence in their mathematical abilities. In addition, specific concepts, such as ratio and proportion, fractions, and decimals, are useful for a variety of engineering design projects. Understanding these concepts is closely linked to success in algebra, which is a gatekeeper course for advancement in STEM education (NMAP, 2008).

RECOMMENDATION 3. The National Science Foundation and/or U.S. Department of Education should fund research to determine how science inquiry and mathematical reasoning can be connected to engineering design in K–12 curricula and teacher professional development. The research should be attentive to grade-level differences in classroom environment and student cognitive development and cover the following specific areas:

- the most important concepts, skills, and habits of mind in science and mathematics that can be taught effectively using an engineering design approach;
- the circumstances under which students learn important science and mathematics concepts, skills, and habits of mind through an engineering-design approach as well or better than through science or mathematics instruction;
- how engineering design can be used as a pedagogical strategy in science and mathematics instruction; and
- the implications for professional development of using engineering design as a pedagogical tool for supporting science and mathematics learning.

Technological Literacy and K–12 Engineering Education

Technology in K–12 engineering education has primarily been used to illustrate the products of engineering and provide a context for thinking about engineering design. However, using engineering to explore ideas consistent with other elements of technological literacy, such as the nature and history of technology and the cultural, social, economic, and political dimensions of technology development are less prevalent.

A number of concepts important to understanding the nature of technology, such as systems, optimization, and trade-offs, are salient to engineering design. The way technology has influenced the course of human affairs provides a natural bridge to other K–12 subjects, such as social studies and history. For students to have an appreciation of the value and limits of engineering, they should have an understanding of the nontechnical dimensions of technology, such as an awareness that all technologies can have unintended consequences and that the decisions to develop and use a technology necessarily involve ethical considerations.

The committee believes that the value of K–12 engineering curricula and of professional development for teachers of K–12 engineering would be

increased by stronger connections to technological literacy, as described in such documents as the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000).

Professional Development Programs

Finding 9. As reflected in the near absence of pre-service education as well as the small number of teachers who have experienced in-service professional development, teacher preparation for K–12 engineering is far less developed than for other STEM subjects.

Nearly all teacher in-service initiatives for K–12 engineering education are associated with a few curriculum projects. Many of these professional development initiatives lack one or more of the characteristics known to lead to teacher learning, such as professional development that lasts for a week or longer, ongoing in-classroom or online support following formal training, and opportunities for continuing education. No active pre-service initiatives seem likely to contribute significantly to the supply of qualified engineering teachers in the near future. Indeed, the qualifications for an engineering educator at the K–12 level have not even been defined. Thus, although graduates of a handful of teacher-preparation programs have strong backgrounds in STEM subjects, including engineering, few if any of them appear to end up teaching K–12 engineering classes.

The reader should keep in mind the important differences between elementary and secondary schools and between teachers in these two branches of the K–12 education system. At the elementary level, separate courses for individual subjects and teachers with special credentials, for example, a licensed "engineering teacher," are very rare. At the secondary level, teacher specialization is more common. Thus approaches to professional development vary depending on grade level.

According to input from the workshops and public comments on the committee's project summary report, many K–12 teachers are unfamiliar with engineering, do not have content knowledge in science, and have relatively little preparation for teaching mathematics. All of these factors are certain to make in-service professional development for engineering education less effective. Furthermore, no accepted model for professional development for K–12 engineering has yet been developed. However, based on research in other domains, such as mathematics and science, we can get a good idea of successful approaches to preparing teachers in engineering.

Current K–12 engineering teachers come predominantly from the ranks of technology educators. Only a few science and math teachers teach engineering; even fewer engineers have become K–12 teachers. The lack of certification or licensing for "engineering" teachers, which is an issue at the secondary school level, reflects the relative newness of the field and uncertainties about the knowledge and pedagogical skills engineering teachers need to be competent. Over the long term, it is not clear where future engineering teachers for K–12 will come from, which could delay the acceptance of K–12 engineering education as a mainstream component of the school curriculum.

RECOMMENDATION 4. The American Society of Engineering Education (ASEE), through its Division of K–12 and Pre-College Education, should begin a national dialogue on preparing K–12 engineering teachers to address the very different needs and circumstances of elementary and secondary teachers and the pros and cons of establishing a formal credentialing process. Participants in the dialogue should include leaders in K–12 teacher education in mathematics, science, and technology; schools of education and engineering; state departments of education; teacher licensing and certification groups; and STEM program accreditors. ASEE should consult with the National Center for Engineering and Technology Education, which has conducted research on this topic.

Diversity

Finding 10. Based on evaluations, anecdotal reports, and our own observations, lack of diversity is a serious issue for K–12 engineering education.

As was noted in Chapter 2, the lack of diversity in post-secondary engineering education and the engineering workforce in the United States has been well documented The diversity problem in K–12 engineering is manifested in two ways. First, the number of girls and underrepresented minorities who participate in K–12 engineering education initiatives does not correspond to their proportion of the general population. Second, with a handful of exceptions, curricular materials do not portray engineering in ways likely to be meaningful to students from a broad range of ethnic and cultural backgrounds. Such students often have life experiences and technological interests different from those of the curriculum developers or of the majority culture.

For K–12 engineering education to yield the benefits its supporters claim for it, access and participation will have to be broadened considerably, if only because, according to predictions, the U.S. population will shift to "majority minority" by midcentury (U.S. Census Bureau, 2008). Thus ensuring that a wide range of K–12 students have an opportunity to experience engineering education will require reaching out to diverse groups and may lead, in the long run, to a more diverse technical workforce, which some have argued will be more capable of anticipating and addressing the technological needs of a diverse society and a global marketplace (Page, 2007).

Attracting girls and minority students to K–12 engineering education will require pro-active efforts by curriculum developers, teachers, providers of professional development, and supporters of these efforts. These efforts could include more effective communication about the work of engineers and how it contributes to human welfare. As part of a recent project at the National Academy of Engineering, messages for improving public understanding of engineering were developed and tested for their effectiveness and appeal to young people of all backgrounds (NAE, 2008). Tests on teens and adults, including large samples of African Americans and Hispanics, showed that the most effective messages stress the beneficial impacts of engineering on people and the environment.

RECOMMENDATION 5. Given the demographic trends in the United States and the challenges of attracting girls, African Americans, Hispanics, and some Asian subpopulations to engineering studies, K–12 engineering curricula should be developed with special attention to features which appeal to students from these underrepresented groups, and programs that promote K–12 engineering education should be strategic in their outreach to these populations. Both curriculum developers and outreach organizations should take advantage of recent market research that suggests effective ways of communicating about engineering to the public.

POLICY AND PROGRAM ISSUES

Many questions remain to be answered about the best way to deliver engineering education in the K–12 classroom and its potential on a variety of parameters of interest, such as science and mathematics learning, technological literacy, and student interest in engineering as a career. Despite these uncertainties, engineering is already being taught in K–12 schools scattered around the country, and, the trend appears to be upward. Given this situa-

tion, it is important that we consider the best way to provide guidance and support to encourage this trend.

An underlying question for policy makers is how engineering concepts, skills, and habits of mind should be introduced into the curriculum. There are at least three options along a continuum in terms of ease of implementation—ad hoc infusion, stand-alone courses, and interconnected STEM education.

- Ad hoc infusion, the introduction, or infusion, of engineering ideas and activities (i.e., design projects) into existing science, mathematics, and technology curricula is the most direct and least complicated option, because implementation requires no significant changes in school structure. The main requirements would be (1) willingness on the part of teachers and (2) access to instructional materials. Ideally, teachers would also have a modicum of engineering pedagogical content knowledge to deliver the new material effectively. The ad hoc option is probably most useful for providing an introductory exposure to engineering ideas rather than a deep understanding of engineering principles and skills.
- Stand-alone courses for engineering, an option required for implementing many of the curricula reviewed for this project, presents considerably more challenges for teachers and schools. In high schools, the new material could be offered as an elective. If that is not possible, it would either have to replace existing classes or content, perhaps a science or technology course, or the school day would have to be reconfigured—perhaps lengthened—to accommodate a new course(s) without eliminating existing curriculum. Stand-alone courses would also require teacher professional development and approval at various levels (e.g., state department of education, school board). This option has the potential advantage of providing a more in-depth exposure to engineering.
- Fully interconnected STEM education, that is, using engineering concepts and skills to leverage the natural connections between STEM subjects, would almost certainly require changes in the structure and practices of schools. Research would be necessary to develop and test curricula, assessments, and approaches to teacher professional development. New interconnected STEM programs or “pilot schools” might be established to test changes before they are widely adopted.

The three options just described, as well as others that are not described here, are not mutually exclusive. Indeed, the committee believes that implementation of K–12 engineering education must be flexible because no single approach is likely to be acceptable or feasible in every district or school. To illustrate the need for flexibility, three case studies of schools that have made engineering a significant part of their curricula can be found in the annex to this chapter.

Broader inclusion of engineering studies in the K–12 classroom also will be influenced by state education standards, which often determine the content of state assessments and, to a lesser extent, curriculum used in the classroom. Forty states have adopted the technological literacy standards developed by the International Technology Education Association, which contain a number of learning goals related to engineering design (Dugger, 2007). However, only 12 states require students to take coursework in technology education as a requirement of graduation.

It is worth noting that the No Child Left Behind Act of 2001 (P.L 107-110) puts considerable pressure on schools and teachers to prepare K–12 students to take annual assessments in mathematics, reading/language arts, and science,[8] and these assessments are based on state learning standards. Thus NCLB currently provides little impetus for teaching engineering.

Plans for implementing changes to include engineering in a school curriculum at any level must take into account places and populations (e.g., small rural schools, urban schools with high proportions of students of low socio-economic status, etc.) with a limited capacity to access engineering-education resources.

Another important element of implementation is the "technical core" of education, that is, what actually happens in the classroom between the teacher, the student, and the content (Elmore, 2000). In many respects, this is where real change and improvements in teacher practice and student learning occur. However, it is also very difficult for reformers to gain access, because schools have structures and traditions to isolate this core from the effects of change. One way to gain access might be to work toward "coherence," that is, to create educational systems in which standards, curricula, professional development, and student assessments are aligned and school leadership supports the need for change. A recent report from the National Science Board (NSB, 2007) calls for more coordination among stakeholders

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[8]Unlike in mathematics and reading, scores from the science assessments are not used to judge states' progress toward so-called Adequate Yearly Progress, a measure of the proportion of children who are meeting or exceeding specified achievement levels.

in STEM education and urges the development of national STEM content guidelines and student assessments as part of an effort to encourage "horizontal coordination and coherence." Although the current situation for K–12 engineering shows little evidence of coherence, working toward greater coherence is an important, long-term objective.

The committee believes that, ideally, all K–12 students in the United States should have the option of experiencing some form of formal engineering studies. We are a long way from that situation now.

RECOMMENDATION 6. Philanthropic foundations or federal agencies with an interest in STEM education and school reform should fund research to identify models of implementation for K–12 engineering education that embody the principles of coherence and can guide decision making that will work for widely variable American school systems. The research should explicitly address school populations that do not currently have access to engineering studies and take into account the different needs and circumstances of elementary and secondary school populations.

K–12 engineering also has policy and program implications for the articulation between high school and college. If K–12 engineering education emphasizes design activities, then two- and four-year post-secondary institutions may have to place early emphasis on design projects to avoid "turning off" students who expect that experience in their first year. Schools of engineering and other post-secondary institutions may also have to improve interactions among science, mathematics, and technology departments to accommodate the expectations of students who have experienced interconnected STEM education in high school.

Finally, the need for qualified teachers to teach engineering in K–12 classrooms raises a number of policy and program issues. Putting aside the uncertain definition of "qualified" in this context, it is not clear that solutions are available that can be funded, accommodated in the current structure of schools, and sustained. A variety of traditional and alternative mechanisms should be evaluated as part of the initiative suggested in Recommendation 4.

INTEGRATED STEM EDUCATION

Perhaps the most compelling argument for K–12 engineering education can be made if it is not thought of as a topic unto itself, but rather as part of integrated STEM education (Box 6-1). After all, in the real world engineer-

ing is not performed in isolation—it inevitably involves science, technology, and mathematics. The question is why these subjects should be isolated in schools. This same issue was raised by Project 2061 of the American Association for the Advancement of Science more than 15 years ago, long before the STEM acronym appeared on the scene (AAAS, 1993, pp. 321–322).

> By "science," Project 2061 means basic and applied natural and social science, basic and applied mathematics, and engineering and technology, and their interconnections—which is to say the scientific enterprise as a whole. The basic point is that the ideas and practice of science, mathematics, and technology are so closely intertwined that we do not see how education in any one of them can be undertaken well in isolation from the others.

BOX 6-1
"Integrated" STEM Education

The committee chose to use the word "integrated" to describe its vision for STEM education, in part because this term is in wide use already within the education community. The modest literature that examines efforts at integration in STEM education mostly concerns science and mathematics (e.g., Berlin and Lee, 2005; Pang and Good, 2000) and, occasionally, science and technology (e.g., Geraedts et al., 2006). Integration suggests connections on at least one and perhaps many levels, including curriculum, professional development, instruction, and standards, in concert with supporting policies at the school, district, or state level. A major barrier to discerning which integration approaches may be effective and why is that researchers and practitioners appear to have no common definition of what integration means (Hurley, 2001). In addition, some types of integration may have higher barriers to implementation than others (e.g., Czerniak et al., 1999). For example, integration may require a high level of teacher content and pedagogical content knowledge in multiple STEM fields. Other models of integration, with lower barriers to implementation, might rely on content specialists in individual STEM disciplines to introduce students to key concepts in those areas. Some concepts would be reinforced or elaborated through connections to other subjects. For example, the design process could be taught by a biology teacher in the context of biomimicry or by a physics teacher exploring assistive technologies. Schools could facilitate this kind of integration by co-locating STEM teaching areas, identifying STEM "teams," providing time for STEM teachers to coordinate lesson plans, and encouraging STEM teams to redesign existing activities to emphasize connections.

Finding 11. Although the term "STEM education" is used in national education policy, it is not implemented in a way that reflects the interdependence of the four STEM subjects.

Although the committee did not target K–12 STEM education initiatives specifically, based on the personal experience and judgment of committee members, the great majority of efforts to promote STEM education in the United States to date focus on either science or mathematics (generally not both) and rarely include engineering or technology (beyond the use of computers). By contrast, the committee's vision of STEM education in U.S. K–12 schools includes all students graduating from high school with a level of "STEM literacy" sufficient to (1) ensure their success in employment, post-secondary education, or both, and (2) prepare them to be competent, capable citizens in a technology-dependent, democratic society. (The three school case studies described in the annex to this chapter represent varying degrees of STEM integration.) Engineering education, because of its natural connections to science, mathematics, and technology, might serve as a catalyst for achieving this vision. The committee was not asked to determine the qualities that would characterize a STEM-literate person, but making such a determination would be a worthwhile exercise.

RECOMMENDATION 7. The National Science Foundation should support research to characterize, or define, "STEM literacy," including how such literacy might develop over the course of a student's K–12 school experience. Researchers should consider not only core knowledge and skills in science, technology, engineering, and mathematics, but also the "big ideas" that link the four subject areas.

Pursuing a goal of STEM literacy in K–12 will require a paradigm shift by teachers, administrators, textbook publishers, and policy makers, as well as by scientists, technologists, engineers, and mathematicians involved in K–12 education. Standards of learning, instructional materials, teacher professional development, and student assessments will have to be re-examined and, possibly, updated, revised, and coordinated. Professional societies will have to rethink their outreach activities to K–12 schools in light of STEM literacy. Colleges and universities will have to cope with student expectations that may run counter to traditional departmental stovepipe conceptions of courses, disciplines, and degrees.

Why do we suggest such a comprehensive change? First, the committee believes that STEM-literate students would be better prepared for life in the twenty-first century and better able to make career decisions or pursue post-secondary education. Second, interconnected STEM education could improve teaching and learning in all four subjects by reducing excessive expectations for K–12 STEM teaching and learning. This does not mean that teaching should be "dumbed down," but rather that teaching and learning in fewer key STEM areas should be deepened and that more time should be spent on the development of a set of STEM skills that includes engineering design and scientific inquiry.

A FINAL WORD

In the course our efforts to understand and assess the potential of engineering education for K–12 students, the committee underwent an epiphany of sorts. To put it simply, for engineering education to become more than an afterthought in elementary and secondary schools in this country, STEM education as a whole must be reconsidered. The teaching of STEM subjects must move away from its current siloed structure, which may limit student interest and performance, toward a more interconnected whole. The committee did not plan to come to this conclusion but reached this point after much thought and deliberation.

We feel confident that our instincts are correct, but other organizations and individuals will have to translate our findings and recommendations into action. Meaningful improvements in the learning and teaching of engineering and movement toward integrated STEM education will not come easily or quickly. Progress will be measured in decades, rather than months or years. The changes will require a sustained commitment of financial resources, the support of policy makers and other leaders, and the efforts of many individuals both in and outside of K–12 schools. Despite these challenges, the committee is hopeful that the changes will be made. The potential for enriching and improving K–12 STEM education is real, and engineering education can be the catalyst.

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Annex

THREE CASE STUDIES

High Tech High

At High Tech High in San Diego, engineering instruction is integrated not only with the other STEM subjects (science, technology, and mathematics), but also with many other subjects, including art, writing, and literature. High Tech High is a compelling example of how engineering can be woven into the fabric of a high-school curriculum.

High Tech High was founded in 2000 by a group of San Diego educators and business leaders as a charter high school. Since then, it has grown to include five high schools, two middle schools, and one affiliated elementary school. The goal of High Tech High is to provide students with personalized, project-based instruction (High Tech High, 2008a). Teachers work closely with students, adapting class content to individual learners. Students take only four subjects per semester, instead of the usual six or seven, to ensure that the curriculum remains focused. The school has no sports teams, no marching band—just academics.

Class sizes are small—generally 20 to 25 students—as is the student body. In 2008, the eight schools that make up High Tech High had a total of 2,500 students; even the oldest and largest of the eight, Gary and Jerri-Ann Jacobs High Tech High, had only 490 students in grades 9 through 12 (High Tech High, 2008b).

The success of High Tech High in teaching students from diverse backgrounds has been widely reported (e.g., Murphy, 2004). Students are selected by lottery from a pool of applicants from all over San Diego County; no aptitude tests or assessments are required for admission. Yet every high school student graduates, and every one of the graduates has been accepted to a college, 80 percent to four-year colleges and universities (High Tech High,

2008a). About 35 percent of High Tech High graduates so far have been the first in their families to attend college, some the first to finish high school. Colleges attended include Stanford, University of California at Berkeley, Massachusetts Institute of Technology, Yale, Dartmouth, Georgetown, Northwestern, and Rensselaer Polytechnic Institute. More than 30 percent of High Tech High alumni enter a science, engineering, or mathematics field, compared with a national average of 17 percent (High Tech High, 2008c).

Engineering has been taught at High Tech High almost since its inception. Near the end of the inaugural 2000–2001 school year, David Berggren was hired to be an engineering instructor starting in the fall of 2001. Like a number of other teachers at the school, Berggren did not have a traditional teaching background. He studied engineering at the California Maritime Academy, where he earned a B.S. in marine engineering technology with a minor in computer science; he then worked for several years on factory fishing trawlers in the Bering Sea. In 2000 and 2001, he worked with his father to build, from scratch, a 58-foot steel salmon-fishing boat, which was delivered to its owners in Alaska in May 2001. By that time, looking for something different to do, Berggren had applied for the teaching position at High Tech High and had been accepted.

With no formal training on how to teach engineering to high school students—indeed, with no background in education at all—Berggren turned to the Project Lead the Way (PLTW) program, which, he says, was a "lifesaver." PLTW provides a variety of well developed modules and courses that can be taught as is to engineering students. Berggren found that by using PLTW, he was able to focus his attention on aspects of teaching other than course development. For his first course, on the principles of engineering, he used PLTW's course materials. As he became more comfortable and familiar with the materials and with teaching, he began modifying PLTW material to suit his students' needs and his own ideas of the best way to teach the subject.

Berggren found himself teaching different areas of engineering, depending on the students' interests and on the other teachers with whom he was collaborating at the time. To do this, he had to ask himself exactly what his students should be learning about engineering. "Over the years, it's something I really struggled with—what is common across the different fields of engineering." Ultimately, he says, he decided that the most important thing was for the students to learn and be able to use the design process. "I feel like this design process is not only common to all areas of engineering, but it's something that can be applied to all areas of life," he says.

In the past few years, Berggren has been teaching engineering design principles to seniors at High Tech High who must all complete a senior project (a large, complex project, sometimes combined with a few small projects to help them get started). Berggren is one of six teachers teaching these seniors; the others are an art teacher, a multimedia teacher, a physics teacher, and two English teachers. The students rotate through four of them, two each semester, so that one group of students may take, for example, art and physics in the fall and English and engineering in the spring. Each semester course is actually a double course that takes up half the day; by the end of the year students have taken a full-year equivalent of art, physics, English, and engineering. "In the past we let the seniors choose their disciplines," Berggren says, "but we decided we wanted to expose them to as much as possible." Now the school decides which of the four classes each senior will take. "We're constantly changing," Berggren says, "trying new things."

Whenever possible, the senior-project teachers collaborate so no matter which courses a particular student takes in a given semester, he or she will be taught with an emphasis on various connections and common subjects. This is easier to do for some pairings than others, Berggren notes. When he was paired with the art teacher, for instance, they worked on creating pots. In the spring 2008, he was paired with an English literature teacher, and they did mostly separate things.

Over the years, Berggren says, he has found that the most difficult thing for students working on a senior project with an engineering component has been to identify the problem that had to be solved. So, before the 2007–2008 school year, he traveled to Purdue University to be trained in their Engineering Projects in Community Service (EPICS) program. EPICS students work in design teams to solve problems for nonprofit organizations in the local community (Coyle et al., 2005). Originally developed for students in college engineering classes, EPICS is now being tested in 15 to 20 high schools around the country, including High Tech High.

Today, instead of students trying to come up with a design problem on their own, Berggren has them begin by researching nonprofit organizations in the community. Once a group of students decides on a nonprofit they would like to work with, they set up a meeting with members of that organization to discuss what they can design to help the organization run better or to do things it can't do. "The students identify a problem, research it, see what's been done, come up with solutions, settle on a design, build it, test it, and deliver it to the organization," Berggren says. "They have a real customer—it's not me telling them what to do. And it gives them more 'buy in' because they are selecting the organization."

In one case, Berggren describes how his students worked with the local chapter of United Cerebral Palsy to design a specialized paper holder for a woman with visual problems. To keep her place on a line of words as she was typing, she had an assistant move a bar along the paper for her. The students created a motor-driven system "that allows her to move the bar up and down herself," Berggren says. "She was just beaming with excitement and joy, and the students were really excited. They felt they had really done something to change this person's life."

In addition to PLTW and EPICS, Berggren also works with US FIRST, an organization started by the inventor Dean Kamen to inspire young people's interest in science and engineering (FIRST is an acronym for For Inspiration and Recognition of Science and Technology). US FIRST sponsors and organizes robotics competitions in which teams of students have six weeks to solve a particular problem using a standard parts kit and a common set of rules (US FIRST, 2008).

Berggren sponsors a team for his students as an extracurricular activity. About 30 students participate, including students from other schools in the High Tech High system. Besides designing and building their robot, the students also make presentations at schools, conferences, and local fairs. US FIRST expects the team to run itself as a corporation, Berggren says, with the goal of learning how engineering is done in the real world. Many late nights and weekends are spent working, he says. "I do it because you see what the kids get out of it."

The kids also get much out of the High Tech High engineering classes, he says, especially "an understanding of and an interest in engineering." Of the 80 students in his engineering classes over the course of a year, he estimates that about 15 to 20 percent pursue engineering in college. And, he says, at least a few of them tell him something along the lines of, "I had no idea what this was, it never crossed my radar screen, but now I want to go on to college and study engineering."

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Texarkana ISD K–16 Engineering Collaborative

Texarkana Independent School District (TISD) and Texas A&M University-Texarkana have forged a powerful partnership. Working together, they are building a pipeline for students well versed in science, technology, engineering, and math (STEM) education from kindergarten through college. This model, the first of its kind in the country, may turn out to be one that can be replicated in other school districts.

The planning for the program, officially called the Texas A&M University-Texarkana—Texarkana ISD K–16 Engineering Collaborative—began in January 2005, when a blue-ribbon committee of TISD had its first meeting. Members of the committee included parents, community and business leaders, and school district representatives. The purpose of the meeting was to review the school district's facilities and programs and determine how to improve its STEM program. This committee had a strong incentive—a need for more engineers at the local level to support businesses, such as International Paper, Domtar Paper Mill, and Alcoa.

As plans for the K–16 vertically aligned program evolved, the planning committee received good news. The family of Josh Morriss, Jr., donated land near the Texas A&M-Texarkana campus for the new K–5 elementary school. The first piece of the K–16 pipeline, this school, called the Martha and Josh Morriss Mathematics and Engineering Elementary School, focuses on math, science, and engineering.

The new school opened its doors in the fall of 2007, with Principal Rick Sandlin at the helm. Students apply to attend the school and are selected on a first-come-first-served basis. The school's first cohort of 396 students has about 23 percent African American, Hispanic, Asian, and American Indian students and 15 percent from low-income households. No matter where the students live or what their backgrounds are, they are all expected to live up to the school's high standards.

The planning team of TISD decided to develop its own engineering curriculum working with faculty from Texas A&M to design K–5 learning units that would be age-appropriate, hands-on, and conceptually based. The units are also aligned with the Texas Essential Knowledge and Skills (TEKS) curriculum, so students will be prepared for the state exams given each year.

The school day begins with engineering. Students work on units covering many topics, such as problem solving, architecture, weather and space, bioengineering, forces of motion, robotics, and engineering structures. "Our goal is to teach as much engineering as we can," explains Sandlin. "We teach the engineering process of 'imagine, plan, design, improve, and share' in the engineering program, as well as throughout the curriculum." At the end of many of the six-week units, students participate in an Engineering Encounter, a presentation for parents and community members to showcase what they have learned. The event also serves as an embedded assessment.

Just as students are held to high standards, so too are teachers. Every teacher in the school must have a master's degree and either Texas Master Mathematics Teacher Certification or Texas Master Technology Teacher Certification, both of which can be obtained through programs at Texas A&M. For teachers who do not yet have a master's degree, the district pays for coursework if the teacher makes a commitment to stay at the school for four years.

In addition to educational requirements, teachers also must take two courses in curriculum design and curriculum delivery designed by Texas A&M faculty specifically for this program. Throughout the school year, the school curriculum coach works with teachers by conducting weekly planning sessions. "We're working on raising the bar in the way we teach engineering," says Principal Sandlin.

By all accounts, these efforts have paid off. In the first year of the program, 98 percent of the students in grades 3 through 5 scored high enough on the state exam to meet the standards in math. Fifth-grade students also take a science assessment test, and 98 percent of them also met those standards. Perhaps even more important, the students clearly enjoy the program. Even though the academics are difficult, most students opt to stay at the school. Of the 396 kids admitted in the first year, only 25 left. The school is already at capacity for the upcoming school year.

In the fall of 2008, the district expanded the engineering program to include the sixth grade. Creating a "school within a school" at Texas Middle School, the district is adding two STEM-related components. The first is a

modular program called Synergistic Technologies, a series of science and technology units with an emphasis on problem solving. Working in pairs, students use a combination of hands-on activities and technology to explore a range of topics, including biotechnology, heat and energy, and light and lasers. The modules encourage students to work independently, with the teacher acting as a guide and facilitator.

To prepare for the new academy structure at the middle-school level, all sixth grade teachers participated in a training program in the summer of 2008. The program included an accelerated version of the curriculum design and curriculum delivery courses designed for Morriss Elementary School teachers and is meant to prepare the sixth grade teachers to use inquiry-based, hands-on instructional methods. "If the modules work well in sixth grade, we may consider using them in the seventh and eighth grades, which will be added over the next couple of years," explains Ronnie Thompson, assistant superintendent for school improvement.

The second addition to the middle school program is an accelerated math course for sixth graders, which introduces the main concepts of algebra. This course gives students the background they need to take Algebra I in seventh grade.

By taking the elementary engineering program and the new STEM offerings in middle school, students will be prepared to take the engineering courses already in place at the district high school. As part of the partnership with Texas A&M, a faculty member teaches two electrical engineering courses on the high school campus. Students who take these courses receive both high school and college credit. Other engineering courses at the high school level include AutoCAD and upper level math courses, including statistics and calculus.

"We want to see the program all the way through," says Thompson. "Over the next several years, we will be collecting longitudinal data to determine how many of the 66 kids per grade from the new elementary school program stay with engineering through high school and beyond. While building a strong engineering pipeline, we also want to build a model program that gives all students a strong foundation in math and science."

Denver School of Science and Technology

When the Denver School of Science and Technology (DSST) opened its doors in 2004, it had two goals: (1) to serve an economically and socially diverse population and (2) to ensure that this population succeeded in the

school's rigorous science, technology, and engineering curriculum. Since then, DSST has come a long way toward realizing those goals. A college preparatory charter school in the Denver Public School (DPS) system, DSST selects students by lottery. Adding one grade a year, the school now serves all four high school grades; the sixth grade (in middle school) was added in fall 2008. Of the 425 high school students, about 34 percent are African American; 24 percent are Hispanic; and 34 percent are white. About 45 percent are girls, and 46 percent come from low-income households.

"We are a diverse school for a reason," explains Bill Kurtz, who heads the school. "You are going to be living and working with people who are different from you. Part of our goal in this school is to say, 'We have people from all backgrounds, and we are about demonstrating that a community of people can use that difference as a strength.'" Indeed, a close-knit community is integral to the school's culture, which emphasizes hard work and success. But DSST does not expect students to meet these high standards alone. Many mechanisms are in place to ensure that none of them slips through the cracks.

The school day begins with a school-wide meeting to give students and faculty an opportunity to share problems, successes, and issues of concern. Each student is also part of a small bi-weekly advisory class that offers help and support on a smaller scale and closely connects each student with an adult in the school. If students come to school with homework uncompleted, they must stay after school that day to finish it. Tutoring also is available after school. These strategies exemplify how all members of the school live by its core values of respect, responsibility, integrity, courage, curiosity, and doing your best.

Students also exemplify the school's values by working hard to master the rigorous curriculum. The engineering curriculum was designed by University of Colorado, Boulder, professors and DSST teachers. The goal is to interest students in the possibility of studying engineering in college. Although the emphasis in ninth and tenth grade is on building a strong foundation in the liberal arts, students performing at grade level in mathematics and reading can begin taking engineering electives in ninth grade. These design-based courses range from fashion engineering to biomimicry.

In their senior year, students can choose to focus on a physics/engineering program or a biochemistry/biotechnology program. Among the seniors who graduated in 2008, two-thirds opted to specialize in engineering. Those students took both an engineering course and an advanced physics course, which included how physics can be applied to engineering design.

Academic expectations at the school are high. To graduate, all students must pass pre-calculus and complete five core lab-based science courses (physics, chemistry, biology, earth science, and physics/engineering or biochemistry/biotechnology), four years of college preparatory language arts, three years of Spanish, and two electives. "The culture of our school stresses engineering and applied math and science degree paths and careers more than any other school I have seen," says Mark Heffron, head of the math department, who has two engineering degrees. "Engineering is often stressed as a reason for learning something in a math or science class."

Another way DSST strives to make the curriculum relevant to students' lives is through an internship program. All high school juniors must complete a 10-week internship, which involves "going to work" for about eight hours a week. Ideally, the students work with a mentor who evaluates their progress and is in regular contact with the school. Throughout the internship, students keep a journal and complete other projects as assigned.

Students can choose either an engineering- or science-based internship; 10 to 15 percent opt for an engineering internship. HDR, Inc, is an engineering and architecture firm that often works with students from DSST. According to Terry Heffron, project manager at the company, "We have students analyzing bridge plans, calculating quantities of concrete needed, and figuring out the linear feet of pipe. By the end of the internship, some students have even progressed to the point where they are doing reinforced-concrete design and preliminary wall layouts. They learn very fast."

During senior year, each student is expected to complete a senior project, which includes an extensive research paper and a work product, such as building a solar car, running a conference, creating a presentation, or producing a film. Again, about 10 to 15 percent choose to complete an engineering-related project.

Through DSST's partnership with the University of Colorado at Boulder, one DSST engineering teacher has been trained directly by university professors; in addition, university engineering faculty teach some engineering courses. Mark Heffron, who teaches math and engineering electives and was a structural engineer before becoming a teacher, brings real-world experience directly to the classroom.

Although the school is still quite new, its scores on standardized math tests are the best in DPS. DSST's first class of ninth graders received the highest scores on the Colorado Student Assessment Program (CSAP) math exams, with 55 percent scoring at the proficient or advanced levels, compared to 17 percent in DPS and 38 percent statewide. Sixty-four percent of DSST

tenth graders scored at the proficient or advanced level, compared to 18 percent in DPS and 31 percent statewide. For two consecutive years, the ninth grade classes have been one of the top two math classes in DPS.

Perhaps even more gratifying than the specific results on test scores has been DSST's rating on a statewide measure that evaluates not only what students know now but how much they have progressed since entering high school. On this key measurement, DSST showed the top growth rate in DPS.

The school's own statistics help explain why. Of the 132 students in DSST's first freshman class, 100 did not pass a proficiency exam and had to attend a three-week summer academy; not all of the kids from this first group stayed with their class. Some left the program altogether, and 15 were held back a year. The 79 students who stayed with their class and persevered are now among the top achievers in DPS, and all 79 have been accepted to four-year colleges or universities. Of these 79 students, 50 percent are the first in their families to reach this milestone. One-quarter of 2008 DSST graduates went on to study engineering in college, and all seniors in the class of 2009 have been accepted into four-year colleges.

Although this is good news for many students, DSST still faces a serious problem. The level of readiness of students coming to DSST hasn't changed significantly in the past three years. About 75 percent of students who take the post-admission proficiency exam continue to need intensive remediation, and some just cannot catch up in four years. This problem is what motivated DSST to open a middle school in the fall of 2008. "We realized that we have to start working with the students sooner," says DSST founder David Greenberg. "By the time they enter high school, they've had eight years of poor education, and for many, it's almost impossible to catch up. We want to help even more kids succeed, and we think that adding grades 6 through 8 to our program will be the most effective approach."

DSST has accomplished much in its first four years, mostly by plain hard work. But the school also had many advantages. An initial challenge grant from the Bill and Melinda Gates Foundation, contributions from corporate, foundation, and philanthropic donors, and a DPS construction bond enabled DSST to build a state-of-the art building that is inviting to students and conducive to learning. "We held focus groups to find out what the kids wanted," says Greenberg. "Girls wanted nooks where they could peel off into small groups. They wanted bright colors and soft furniture. We did all we could to build a 'cool school.'"

In addition, the exposed ductwork and heating and ventilating systems offer a ready-made engineering lesson. The school also is wireless, making it

possible to provide each student with a laptop that works in any part of the building. The new $8 million Morgridge Middle School is the first school in the district built according to guidelines for "green" buildings.

Although other urban schools may not have all of these advantages, they can still learn much from DSST's example. One state has already initiated a project inspired by DSST. The Texas High School Project, a consortium of the Texas Education Agency, the Bill & Melinda Gates Foundation, and the Michael and Susan Dell Foundation, has chosen DSST as one of its best-practices models. The project is creating 35 public STEM (science, technology, engineering and math) secondary schools.

"People ask about how expensive our model is," says Greenberg. "It probably costs about 10 percent more per year than a conventional urban public school. But think about it. We had more minority kids [from DSST] going to the University of Colorado than any other school in the state. We also scored fifth highest in Colorado on the ACT exam. DPS, on the other hand, has a 50 percent drop-out rate. So which model is really more expensive?"